DISCUSSION PAPER

THE NATURE OF ACCEPTABILITY FUNCTIONS IN TEXTURE

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Abstract. This paper provides a psychophysical analysis of potential acceptability functions which may be applicable to food texture responses in particular, and to other stimuli in general. Specific hedonic functions for acceptability would follow a generalized quadratic function, with the parameters governed by the specific food system. A two step combination of simple psychophysical (subjective intensity vs. physical intensity) and psychological (subjective intensity vs. subjective acceptability) relations may provide an easier representation of texture acceptability than predictions derived from the knowledge of physical properties of food (viz. texturogens).

1. Introduction

Drake (1974) has proposed a general model to describe texture acceptability as a function of a wide variety of attributes, including simple perceptual ones, and more complex cognitive ones. The model proposed is meant to be discursive – no function forms are discussed, and thus parameters for the model cannot yet be adduced in Drake's argument. The present paper discusses this approach from the viewpoint of psychophysical measurement and of what is known about man's hedonic responses to stimuli.

The study of hedonics began at least a century ago, in Wundt's laboratory in Germany, during the early period of experimental psychology. Wundt (see Beebe-Center, 1932) had speculated that, whereas the intensity of a stimulus would be faithfully mirrored by our perception (so that increments in stimulus intensity would appear subjectively to be increments in perceived intensity), the degree of liking (or affect) would not follow this linear (or monotonic) course. Rather, for all continua, the affect increases with stimulus intensity, reaches a maximum level, and then decreases. Figure 1 shows Wundt's general scheme. One should be aware that the scheme was meant only to describe processes, and that Wundt himself did not appear to have reported any functions for liking/disliking as related to stimulus intensity (see Beebe-Center, 1932 for a full discussion of the early work leading up to this approach, and the studies of affect engendered by Wundt's speculations).

Subsequent work in the sensory and hedonic evaluation of simple stimuli bore out Wundt's contention, often dramatically. Engel (1928) confirmed it for taste pleasantness, and subsequent researchers obtained similar results using methods of category and

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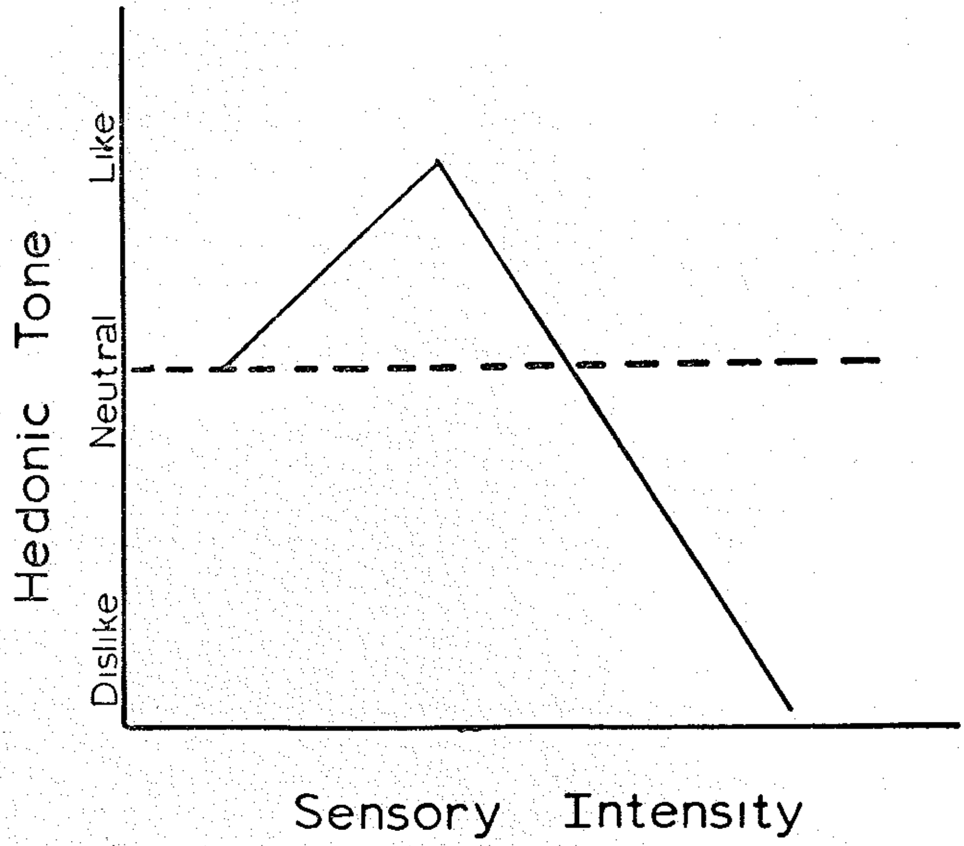

Fig. 1. Schematic relation between sensory intensity and perceived liking/disliking. The exact curvature, maximum point of liking, positions of cross-over from liking to disliking, etc., are subject to the particular parameters of an experiment.

magnitude estimation scaling (Moskowitz, 1975). Wundt's scheme also appears to hold for the hedonic evaluation of odorants (Moskowitz *et al.*, 1975) and for the affect as a function of stimulus complexity (Vitz, 1966).

Relatively little work has been reported on the parameters of the pleasantness functions for texture attributes, although a study by Ekman *et al.* (1956) on the perceived graininess (roughness, smoothness) of sandpaper of varying grit size revealed that pleasantness (by magnitude estimation) and perceived smoothness were not only positively correlated, but also grew in magnitude according to the same power function (exponent value *ca.* 1.5). Moskowitz (1975) suggested that for texture perception of roughness and smoothness these observers appeared to be incapable of distinguishing, at least according to their power functions, between the sensory information imparted by the sandpaper and their hedonic response occasioned by that perception. (Such difficulties in distinguishing between hedonics and sensory information are pervasive and occur for loudness, some odorants, and negative hedonic stimuli for taste such as sourness and bitterness).

Despite the apparent difficulties in distinguishing between the sensory information and the hedonic information for such simple model systems as the roughness of sandpaper, we appear able to decide that foods are too hard or too soft, or that a food is not sufficiently creamy, etc. Hence, any discussion of hedonic functions in texture ought to include the following three stages:

(1) *The relation between the physical magnitude (measured instrumentally) and the perception of sensory magnitude.* Quite often this function is a power function of the form $S = KI^n$ (see Moskowitz and Kapasalis, 1975, for a discussion of the parameters of the power function for textural attributes, such as hardness vs. modulus of elasticity, viscosity vs. apparent centipoises, and roughness vs. grit size).

(2) *The relation between the sensory magnitude and the subjective pleasantness or unpleasantness.* It is quite possible that textural attributes, conveyed as they are by the tactile and kinesthetic systems, do not give rise to immediate, hedonic responses, as do taste and smell stimuli (which often produce innate acceptance and rejection responses). If so, then these hedonic-sensory relations might probably be either lines of a slope of $+1.0$ or -1.0 (so that liking for a single texture attribute grows or declines equally rapidly with sensory magnitude), or lines of a slope of 0 (so that there is no shift in hedonic tone with changes in sensory magnitude). Quite possibly, future studies with other food and non-food systems will suggest power functions having exponents different from $+1$, 0 and -1.

(3) *The relation between the cognitive factors (expectancy of sensory texture) and the perceived sensory texture.* At this stage the observer might respond by one of two ways. If, for example, the sensory hardness of a product exceeds the limitations of hardness that one expects (e.g., an apple is much too hard or much too soft), then the observer might give a single absolute, invariant response to indicate rejection. That is, whenever the sensory precept exceeds the cutoff limits the observer simply provides one fixed hedonic response, independent of the degree to which the texture attribute lies outside the limits. On the other hand, the observer might just as easily 'track' the excess, so that the further away the texture value (e.g., hardness) lies from the ideal region, the greater will be the rating of unpleasantness.

There are other minor points which must be dealt with before any in-depth discussion can be made about hedonic function for texture. For many textural attributes there exist upper and lower sensory bounds. For example, as Harper and Stevens (1964) have shown, once rubber samples pass a certain degree of instrumental hardness (as assessed by the force/deformation ratio) the observer no longer perceives gradations which the instruments might detect. This is recognized for lower-intensity stimuli, where there exist measureable thresholds; for texture perception there also exist upper-level or high thresholds. Increments in physical magnitude are no longer capable of exciting changes in perceptual magnitude. One may consider that virtually all texture attributes exhibit such upper thresholds (viscous materials no longer appear to be liquid, hard stimuli can get no harder, grainy foods no longer appear to be any grainier, etc.). Hence, any analysis of the relation between instrumental, sensory, affective (hedonic) and cognitive properties which determine the overall response of 'liking' or 'disliking' must take into account these upper (and lower) perception thresholds.

2. Forms for Hedonic Functions in Texture

Given the simple hedonic rules outlined above, one of the more naive and simplifying approaches to describe liking and disliking is to assume that the texture levels also conform to Wundt's general scheme for hedonics. For example, for one's liking of crispiness of an apple, there are levels that are too crisp, levels that are not sufficiently crisp, and levels that are in the 'ball park' of ideal crispiness. The general function may be one showing a sharp break, with the maximum being a single physical level (and with the rate of ascent not necessarily being equal to the rate of descent), or a function which shows a region of acceptable levels. The latter, which permits a range, is easier to deal with analytically.

One general function (which may be the simplest) for acceptability (A) relative to sensory magnitude (S) could be written as:

$$A = F(S) = K_1 + K_2 S + K_3 S^2. \tag{1}$$

This is a simple polynomial equation with a given maximum point and with an ascending and a descending part. It can be rewritten as:

$$A = K_4(S + K_5)^2 + K_6 \quad \text{(by completion of the square term).} \tag{2}$$

Since the foregoing equation holds for descriptions of most hedonic functions (vs. sensory magnitude) it ought to hold for texture as well. The sharpness of the ascent and descent, and the location of the maximum (or minimum) point are given by the parameters K_4 and K_5. It should also be noted that the A and S values are obtained by the method of magnitude estimation, where there are fixed and meaningful zero levels. The acceptability measure (A) may permit only positive numbers or may be + for acceptable texture levels, 0 for neither like nor dislike, and − for disliked texture levels. The choice of the scaling procedure (see Moskowitz and Klarman, 1975) influences the parameters of the acceptability equation, but not its general form.

Given that the general function for relating sensory judgments of intensity to physical measures of intensity is a power function of the form: $S = KI^n$, and that the general function for relating acceptability judgments to sensory intensities is a quadratic function (viz. the simplest representation): $A = K_4(S + K_5)^2 + K_6$, then it should follow that to relate physical intensities (I) to acceptability ratings (A) requires the complicated function:

$$A = K_4(KI^n + K_5)^2 + K_6. \tag{3}$$

The shape of this general function will depart increasingly from a simple quadratic function as the exponent n departs from 1.0.

3. Choosing the Appropriate Independent Variables

In order to make the foregoing Equation (3) useful, it is necessary to choose the correct independent variable I (e.g., physical measure). Although the observer can be used to simultaneously evaluating the sensory magnitude and its acceptability, a real understanding of acceptability measures and their extension for instrument and model building will not come unless the experimenter can isolate the variable (set of variables) most highly correlated with physical intensity.

At first glance it might appear reasonable to relate acceptability strictly to instrumental measures. This means instructing the observers to rate the acceptability (A) and then correlating it with instrumental measures (I). The experimenter might search for significant linear and quadratic functions (or other, higher order polynomials) relating A and I, and attempt, experimentally and by means of data analytic techniques, to obtain the parameters of Equation (3). A host of such experiments would probably produce an equally large host of potential values for K_4, K_5, etc. Another procedure may prove to be ultimately better. This is a *two-step* procedure, outlined in a previous study of taste hedonics (Moskowitz and Klarman, 1975).

In this procedure the experimenter first attempts to obtain the power functions (or other classes of functions) relating sensory intensity (S) to physical intensity (I). Since one assumes that such functions are at least monotonic (e.g., with increasing modulus of elasticity one would not expect the observer to state that the food first gets softer rather than harder), the necessity of estimating the additional quadratic curvature parameter is eliminated. In the second phase, the experimenter asks the observer to estimate the degree of liking or disliking, again with the method of magnitude estimation (scaling). This can then be correlated with, or regressed against, the observer's own estimate of sensory intensity. The result is two equations. Their combination produces the desired equation relating acceptance (A) to instrumental measure (I). The advantages of such a two-step procedure are:

(a) Normative data on judgments relating the sensory intensity and the physical magnitude are more common than the acceptability data. Thus, the experimenter may always look for reproducibility in subjective–instrumental correlations prior to descending into the morass of acceptability measures.

(b) Rheological instruments often vary in their reproducibility and in their mechanical properties, as well as show large or small variations in parameters which may or may not be important. The observer integrates all of this information into a single number (sensory magnitude) on which he bases his hedonic ratings, so that sensory magnitude is the most appropriate property with which to correlate acceptability ratings.

4. Considerations on Function Fitting

Any general model of acceptability (whether of food texture or of another cognitive variable) is discursive and descriptive if it is written in mathematical terms, but contains no rules for combination of such variables. These rules may be quite simple, or quite complex, depending upon the state of knowledge in the field, as well as upon the insight, compulsiveness and mathematical expertise of the model developer.

Kramer (e.g., Rasekh and Kramer, 1970) in numerous publications pertaining to quality measurement as a function of physical variables has emphasized the broad applicability of a simple linear regression model of the form:

$$A = K_1X_1 + K_2X_2 \ldots K_nX_n + K_{n+1}. \tag{4}$$

According to Kramer's simplified approach, the panelist is assumed to act as a simple adding device, which first weights instrumental measures (X_i) or subjective variables (X_i may represent subjective estimates of different product attributes) and then sums them up. Such a simple function is easily developed by means of multiple linear regression procedures, e.g., those available by the BMD program series (Dixon, 1967).

In this study of odor quality, Dravnieks (1974) has suggested more complicated functions, including numerous cross terms, to represent the potential or candidate additivity models. In terms of the simple equation above, a more complicated Dravnieks-type of additivity model would posit:

$$A = K_1X_1 + K_2K_2 \ldots k_nX_n + K_{n+1}X_1X_2 + K_{n+2}X_1X_3 \ldots \tag{5}$$

Of course, with increasing numbers of independent terms in the independent variable set the number of interaction terms grows unwieldy.

5. Cognitive Factors in Texture Acceptance

Although the foregoing equations relate instrumental to acceptability measures, and although the parameters of those equations may be reproducible from one experiment to the next, other factors besides sensory inputs affect whether we like or dislike a product's texture. Psychologically, these are called *cognitive* factors and arise from experience and expectations.

Experience. One may come to associate the texture of foods with flavor, degree of ripeness and spoilage. Fruits that are too firm may also be under-ripe, and have as yet undeveloped flavors. The texture of every fruit variety may be idiosyncratically related to its flavor acceptability, and, therefore, to its overall acceptability. Fruits that are too soft and meats that are too tough and stringy may exhibit texture characteristics that by themselves are disliked for those particular foods. The nature of the acceptability function (viz. its curvature, maximum point of acceptability, etc.) will be modified by experiential factors.

Expectations. Closely allied with experience is the expectation of what the texture of a food will be which is often provided by visual cues. If an individual is served (hypothetically) a chewable candy that is exceedingly hard so that it cannot be chewed, or is exceedingly soft so that it dissolves too rapidly in the mouth, then despite the acceptable flavor characteristics the expectation of an appropriate degree of consistency is not fulfilled. Expectations probably have more to do with appreciating texture by itself (for its hedonic properties), whereas experience may have to do with correlating hedonic properties of flavour, etc., with texture as an independent factor.

Of course, simply modeling by first order (two-way) interaction terms may not suffice either. Higher order (three-way interactions) may prevail. Non-linearities in the stimulus–response relationship for single variables (e.g., power functions) may dictate non-linear transforms of the independent variables. Finally, squared, cubic and higher order terms may be required.

Such complexities lead to two different conclusions:

(1) Any present attempt to model the overall acceptability should best be made by taking 'snapshots' of unidimensional relations, e.g., between the acceptability of food texture (or the overall food acceptance), and single, or at most pairwise, sets of physical stimuli. In this manner the form of the unidimensional function can best be discovered. This function often turns out to be a complicated one.

(2) Attempts to model the overall acceptability should strive at determining combination rules, again by means of relating two or three subjective variables to the overall judgments of acceptability. In addition, attempts should be made to relate each subjective variable to one or at most a few well defined mechanical variables. The combination rule of subjective attributes coupled with the psychophysical rules will provide the necessary equation for a model of texture acceptability.

6. Concluding Remarks

The present discussion paper concerns the requirements and potential outcomes for a quantitative representation of acceptability. Were the perceptual system to be linear with respect to (a) the relation between sensory intensity and physical intensity for well defined mechanical variables and sensory attributes, and (b) the relation between acceptability and sensory attributes, then there would be little problem in developing a nicely behaved quantitative relation between physical variables and rated acceptability. Unfortunately, non-linearities in both relations make such a system premature and may – in the final analysis – render the best designed system (such as Drake's) merely a description of which variables interact, rather than a model of how they interact.

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